The effect of graded compression elastic stockings on the lower leg venous system during daily activity

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Purpose: **We evaluated the effects of wearing 20 to 30 mm Hg gradient thigh-length stockings during daily activity on the lower leg venous system.**
Methods: **Twenty-one healthy women volunteers, aged 39 ± 12 years, were examined. One subject was clinical class 4, one was class 2, two were class 1, and the remainder were class 0. The diameter of the posterior tibial, peroneal, and greater saphenous veins were measured at midcalf by means of bilateral duplex ultrasound scanning; calf circumference was measured at the same level. In addition, the number and caliber of all detectable medial calf perforating veins were recorded. Each subject was examined on two separate days, one while wearing the gradient stockings and one not wearing them. Baseline measurements were made on each day before the subjects began their workday, with follow-up measurements made after approximately 4.5 hours of normal activity.**
Results: **Calf circumference increased an average of 23.8 ± 10.1 mm without stockings (P < .001) and decreased by 5.2 ± 7.0 mm when wearing stockings (P = .003). The number of detected perforating veins increased without stockings by 1.8 ± 2.0 at the follow-up examination (P = .002); with stockings, the change was 0.4 ± 1.2 (P = NS).**
Conclusion: **Graded compression elastic stockings help preserve lower leg venous caliber and tone throughout the deep, superficial, and perforating venous systems during normal ambulatory activity, and this may, in part, explain their beneficial effects. (J Vasc Surg 1999;30:830-5.)**

Chronic venous insufficiency (CVI) is a common disorder, affecting as much as 25% of the United States population. Approximately 4% of the population is partially disabled by CVI, and epidemiologic studies indicate that nearly 1% of the population currently has or has experienced leg ulceration.[1] Gradient ambulatory compression therapy was first introduced in the 1950s; it remains the most widely accepted treatment of CVI and is considered the "gold standard."[2] The mechanisms that provide the beneficial effects of compression therapy are still not completely understood, despite a number of investigations. These studies have produced conflicting results regarding the effects of compression therapy on venous hemodynamics and on the surrounding skin and subcutaneous tissue.[3-6] We evaluated the effects of graded elastic compression stockings on the anatomy of the deep, superficial, and perforating veins of the lower leg in healthy volunteers during their normal, ambulatory daily activity.

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METHODS

Twenty-one volunteer subjects were recruited from an outpatient surgery setting in the hospital, which required them to be on their feet most of the time. Before their entry into the study, the experimental protocol was approved by the hospital Institutional Review Board, and each subject gave appropriate informed consent. Each subject had a physical examination of the lower extremities for any findings related to peripheral vascular disease, and each volunteer also completed a brief questionnaire about their medical and surgical history, including specific details of any personal or family history of venous disease. Physical findings of chronic venous

disease were classified according to the reporting standards in venous disease established by an international consensus committee on chronic venous disease held under the auspices of the American Venous Forum.[7] Each volunteer was examined on two separate days, one on which they wore no support stockings of any kind and one during which they wore 20 to 30 mm Hg gradient thigh-length compression stockings. Stockings reaching to midthigh were chosen to provide a continuous pressure gradient throughout the calf and across the knee and to eliminate the possibility of any constricting elastic band across the upper calf.

Baseline data was collected on each day of evaluation early in the morning, before the volunteer's shift began, typically between 6:30 and 7:00 AM, and all measurements were done bilaterally. Volunteers were examined while sitting on a patient stretcher with their lower legs hanging freely in a dependent position. Calf circumference was measured at its greatest dimension. At this same level of the calf, cross-sectional images of the posterior tibial, peroneal, and greater saphenous veins were obtained with a 2-D linear array 7-MHZ high-resolution probe on a Diasonics Gateway scanner (Diasonics Ultrasound, Santa Clara, Calif). With the image focused throughout the region of interest, this probe provided an axial resolution on the order of 0.2 mm to ensure accuracy in the measurement of diameter changes of approximately 1 mm or less. From frozen images, the luminal diameter of each of the paired posterior tibial and peroneal veins and of the greater saphenous vein was measured with the electronic calipers of the duplex system. The luminal diameter of the greater saphenous vein was also measured at a site just above the medial malleolus. Finally, the entire medial calf was scanned by means of color Doppler imaging with manual calf compression and release to identify the presence of medial perforating veins. The number of perforating veins seen in each calf was recorded, and each perforating vein was measured for luminal diameter at the point at which it penetrated the fascia and entered the subcutaneous space. All duplex ultrasound scans were done by a single investigator. Total ultrasound scan time was between 3.5 and 4 minutes per lower leg, and this scan time remained consistent throughout the study. Once baseline data was collected each day, the volunteers carried out their normal job functions, which typically required nearly continuous standing or walking without sitting for the first half of their shift. After a mean interval of 4.28 hours, each volunteer again sat at the edge of the patient stretcher with their lower legs freely hanging, and all measurements were repeated bilaterally. At this time, each volunteer was also asked to subjectively grade how their legs felt with respect to any swelling or aching, using a visual analog scale of 1 (no swelling or aching) to 10 (bursting sensation or painful to walk).

Data were analyzed by means of the paired *t* test, with a *P* value less than .05 considered significant.

RESULTS

The mean age of the volunteers was 39 ± 12 years. By means of a physical examination, 17 subjects were placed in clinical class 0, two subjects were placed in clinical class 1, one subject was placed in clinical class 2, and 1 subject was placed in clinical class 4. The subject in clinical class 4 had had a previous vein stripping; she was the only subject who routinely wore any type of compression stockings at work. The remainder of the subjects had no other pertinent medical or surgical history. Twelve volunteers related a family history of varicose veins.

No significant differences between the two baseline examinations were seen for any of the variables measured. No differences in results were seen between the 17 volunteers in clinical class 0 and the other four subjects, so the data for all volunteers were grouped together. In addition, no significant differences were seen between the right and left lower legs of the subjects; data are expressed by using right- and left-limb measurements combined. For the posterior tibial and peroneal veins, measurements of both of the paired veins were used to determine all vessel caliber changes. The interval during which the subjects worked between baseline and final measurements was the same for the control (no stocking) segment, 4.3 ± 0.4 hours, as for the study (wearing compression stockings) segment, 4.2 ± 0.4 hours ($P = .162$).

The baseline calf circumference was 36.8 ± 2.1 cm. This increased by 2.4 ± 1.0 cm for the no-stocking period ($P < .001$), but showed a small but significant decrease after the wearing of compression stockings, changing by –0.5 ± 0.7 cm ($P = .003$).

When the subjects were not wearing stockings, the lumen diameter of all venous segments measured showed significant increases over baseline (Table I). When stockings were worn, lumen caliber tended to decrease slightly from baseline to final measurements, although these changes were not significant. Comparison of final measurements between the control and the stocking periods showed significant differences for all venous segments, with a *P* value of .001.

At baseline, 4.0 ± 1.3 perforating veins were

Table I. Measurement of venous lumen diameter (mm)

	Without stockings			*With stockings*		
	Baseline	*Change*	*P value*	*Baseline*	*Change*	*P value*
Posterior tibial	4.0 ± 0.9	0.8 ± 1.1	.002	4.3 ± 1.0	–0.4 ± 0.9	.07
Peroneal	5.5 ± 0.8	0.9 ± 0.8	< .001	5.9 ± 0.8	–0.7 ± 0.7	.001
Greater saphenous, midcalf	2.8 ± 0.5	0.5 ± 0.4	.002	3.2 ± 0.7	–0.3 ± 0.6	.18
Greater saphenous, ankle	2.9 ± 0.4	0.6 ± 0.5	.001	3.2 ± 0.5	–0.1 ± 0.5	.48

identified in the right and left lower legs combined. This increased by 1.8 ± 2.0 veins for the control period ($P = .002$) and increased by 0.4 ± 1.2 veins during the period with stockings ($P = .284$). The caliber of the perforating veins increased during the control period by 0.6 ± 0.4 mm ($P < .001$) and decreased by a comparable amount, –0.5 ± 0.3 ($P < .001$), during the period with stockings. Evidence of reflux flow was demonstrated by means of color Doppler imaging in a perforating vein in two subjects, both clinical class 0, while not wearing stockings; no other evidence of perforator vein incompetence was seen in any subject.

At the end of the control period, the mean visual analog score for the feeling of swelling was 4.9 ± 2.9, and the mean visual analog score for aching was 6.9 ± 2.6. At the end of the period with stockings, these scores were 1.7 ± 1.0 for swelling ($P < .001$) and 2.0 ± 1.7 for aching ($P < .001$).

DISCUSSION

The daily activity of persons in jobs that require long periods of standing and walking without rest has been shown to alter normal venous hemodynamics. Bishara et al[8] showed a significant decrease in venous refilling time (VRT) in healthy women subjects after their normal daily activity, which required them to be upright for a minimum of 5 hours, with an abnormal VRT developing 21% of limbs. Katz et al[9] had similar findings in normal subjects, and by using air plethysmography, they showed significant increases in venous filling index and significant shortening of venous filling time, comparing early morning with late afternoon. In that study, 14% of limbs converted from a normal to an abnormal VRT by late afternoon. Labropoulos et al,[10] by using duplex ultrasound scanning, found a significantly higher prevalence of venous insufficiency, predominantly involving the greater saphenous system, in a group of clinically healthy vascular surgeons, compared with the control group of men with occupations not requiring long periods of standing. Whether such changes in venous hemodynamics caused by daily activity eventually produce clinical evidence of chronic venous insufficiency (CVI) is not known.

Compression therapy remains the gold standard for the treatment of CVI, and ambulatory compression stockings remain the most widely used form of this therapy. However, the mechanisms by which graded elastic compression stockings provide their benefit in the control and treatment of venous insufficiency are not clearly understood. Previous studies of the hemodynamic effects of compression stockings have given conflicting results, with some studies suggesting improvement in lower extremity venous hemodynamics and others showing no significant changes in ambulatory venous pressure (AVP) or in VRT.[3,11,12] Mayberry et al,[12] for example, showed no significant changes with below-knee or above-knee graded compression stockings in the AVP or VRT of healthy subjects or in patients with CVI. They did measure significant transmission of the compression pressure of the stockings to the skin, and they also showed a trend toward elevated peak venous flow velocities in the popliteal and common femoral veins, but these changes were generally not significant.

Although our study did not directly address venous hemodynamics, we did find significant differences in the anatomic changes of the lower leg veins caused by normal daily activity requiring continuous standing and walking. When subjects were not wearing graded compression stockings, calf circumference increased, venous luminal diameter consistently increased in all segments evaluated, and the number and size of identified medial calf perforating veins increased. When stockings were worn by subjects during their work day, calf diameter and venous luminal diameters all tended to decrease, although generally not by significant amounts, and there was a minimal change in the number of identified perforating veins. The relationship, if any, between these anatomic changes and any hemodynamic changes remains to be evaluated.

The findings of our study suggest more of a direct anatomic effect rather than a hemodynamic effect, and this may be related to the transmural pressure at

the vein walls. Studies of the characteristics of the vein wall have shown that a vein easily reaches approximately 90% of its volume capacity with a transmural pressure of 40 to 50 mm Hg, after which the vein becomes very "stiff" and does not approach maximal distension until a transmural pressure of approximately 80 to 90 mm Hg is reached.[13] Deterioration of this normal vein wall elasticity has been shown in patients with CVI.[14] In our volunteers, normal ambulatory venous pressure at midcalf should be nearly 80 mm Hg, which in time would cause the stretching of the vein wall that was observed and would account for the increases in venous diameter and calf circumference. Criado et al[15] found no changes by means of duplex ultrasound scanning in proximal venous cross-sectional area after 4 to 6 hours of stationary standing, but their measurements were limited to the femoropopliteal system and the greater saphenous vein at the knee or higher. The study by Katz et al[9] also differs in this respect; they found no significant change in venous volume at the end of the day. However, they do not mention in their report that they controlled in any way for the type of activity in their healthy subjects. If they were allowed to sit or rest periodically during the day, it would relieve the chronic condition of stress and possibly allow the vein wall to recover to a more relaxed state. In our study, the volunteers did not sit, but remained standing or walking for the entire time between measurements, maintaining elevated AVP chronically. These conditions were similar to those of the studies by Bishara et al and Labropoulos et al,[8,10] and although possibly not representative of many persons' usual routine, they were subjectively reported as not significantly different from our volunteers' normal activity.

This chronic strain might also be expected to contribute to the volunteers' subjective feelings of "achy" legs and the sensation of swelling, which they reported by using the visual analog scale during the control phase of the study, when no stockings were worn. However, the scale is highly subjective and likely to lead to a biased outcome because the volunteers could not be blinded to the use of the compression stockings. It is further possible that the expectation of feeling less aching in the legs when wearing the stockings accounts for as much, or more, of the improvement in the overall score as does any actual decrease in lower limb discomfort. The data do support a significant difference in limb swelling with and without stockings, of the same level of statistical significance found by using the visual analog scale. It is not known if this same degree of improvement would be sensed by patients with CVI, and if not, the decreased perceived benefit may be outweighed by the difficulty many patients have in putting these stockings on and lead to the lack of compliance often noted clinically.

The measured effects in this study appear related to the balance of pressures in the lower leg. When subjects were wearing graded compression stockings of 20 to 30 mm Hg, the effective ambulatory transmural venous pressure at midcalf decreased to approximately 50 to 60 mm Hg, allowing the veins to function at near maximal capacity, but without the excessive wall stresses and resulting chronic strain associated with higher AVP. The findings of small, generally nonsignificant changes in lumen caliber and calf circumference support this hypothesis. These findings are also consistent with a hypothesis of an effect of compression stockings in patients with venous reflux being related to improved coaptation of venous valves, as suggested by Sarin et al,[16] although this has never been proved. It also seems reasonable to hypothesize that if it is the goal to keep transmural AVP below 60 mm Hg to prevent progression of venous stasis changes to ulceration in patients with CVI,[17,18] then compression stockings using higher graded pressures of as much as 40 to 50 mm Hg would be necessary, which is the case clinically. In healthy subjects, most of the stocking pressure should be transmitted through the underlying tissue. In patients with CVI, these pressures must be transmitted through several centimeters of edematous and markedly fibrotic tissue, which will attenuate the effect of the stockings.

The role of the perforating veins and how they are affected by compression stockings are not completely understood. Studies have shown an increased prevalence of perforating veins with increasing clinical severity of CVI, but the perforating veins are rarely involved alone in this process.[19,20] No previous studies were found that specifically addressed the effects of compression stockings on the function of perforating veins. Our study showed that anatomically they reacted very much like the deep and superficial veins, significantly dilating when no stockings were worn and decreasing in lumen diameter when stockings were worn. In addition, in the absence of stockings, significantly more perforating veins became prominent and readily detected by means of duplex ultrasound scanning with color Doppler imaging, a technique that has been shown to be sensitive for this task.[19-21] Anecdotally, it was also noted that two perforating veins became incompetent during the day when stockings were not worn,

but without complete studies of the related deep and superficial venous hemodynamics it is not possible to determine the significance, if any, of this information.

We conclude from these data that graded elastic compression stockings help preserve venous caliber and prevent dilation in the deep, superficial, and perforating venous systems of the lower leg in healthy subjects during daily activity that requires nearly continuous standing and walking. Further studies of venous hemodynamics are necessary to determine if this has any relation to the development of venous insufficiency caused by the inability of previously competent venous valves to completely coapt or if other mechanisms may be involved. It is also unknown whether these daily changes in venous caliber are likely to lead to future CVI that can be effectively managed at an early stage with compression stockings, or if they simply represent transient changes that can be readily reversed by rest and leg elevation. All these clinically relevant questions will require further evaluation. Finally, this study examined a group of essentially healthy subjects, who had no evidence of significant chronic venous disease. This was done as an initial study to try to determine the effects of graded elastic compression stockings without the confounding variables introduced by such disease, similar to the approach used for the hemodynamic studies mentioned[8-10] and in the study by Mayberry et al.[12] Although the results of this study may be relevant to the mechanisms by which elastic stockings are effective, it is unlikely that these findings can be extrapolated in many cases to patients with established chronic venous disease, in whom there may be inherent valvular damage and irregular venous channels caused by recanalization of earlier thrombotic episodes.

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DISCUSSION

Dr Simon J. Simonian (Annandale, Va). I thank the society for the opportunity to discuss this interesting and important paper by Dr Buhs and his associates from the Beaumont Hospital in Michigan.

Previous studies in this regard by our current president, Dr Comerota, in a 1994 *Journal of Vascular Surgery* showed that abnormal venous filling index on air plethysmography and a shorter venous refilling time on the photoplethysmography developed in healthy volunteers, indicating abnormality of the venous flow by the end of the afternoon, compared with that in the morning. Labropoulos, a member of our society, in 1995 showed that, on duplex scanning of vascular surgeons on their feet, there was an increase in the greater saphenous vein diameter by the end of the day, compared with healthy controls who did not stand all day. Finally, graduated compression stockings and hemodynamic studies by our past president, Dr O'Donnell, by our secretary, Dr Moneta, and others showed conflicting results on the ambulatory venous pressure and the venous refilling times. So, the first questions are why and how can this discrepancy be answered with your study?

Second, the calf diameter, which increased during exercise without stockings, decreased with stockings. This is being shown for the first time, I believe. Kindly explain that.

Next, Dr Sumner, our current president, has beautifully shown the pressure-volume relationships in the lower leg veins. What is the response of these anatomical changes to hemodynamic changes that you predict with the pressure differences? For example, in the midcalf, the pressure would be approximately 80 mm Hg, whereas in the groin, it would be 45 mm Hg; in the popliteal area, it would be approximately 60 mm Hg; and at the ankle, it would be approximately 90 mm Hg. Dr Criado in 1995 showed no difference in the diameter of the more cephalad proximal popliteal and femoral veins, similar to what you have shown in the midcalf veins. Why this difference? Do you think it is a pressure-related thing—because of the higher pressure in the calf veins than in the proximal veins, there is more increase in their diameter?

There is also an improvement in the visual analogue scale. Was this biased in any way by the volunteers, who knew they were wearing compression stockings and thus might respond with some bias towards your treatment?

Regarding the perforating veins, again it is being shown for the first time that there is a difference in the perforating vein number and diameter. Is this a true and significant observation? Or do you think there is some technical problem associated with these observations?

My next question is about the peroneal vein, which has not been studied as carefully as you have done, indicating that it is really the only vein that shows a difference, which is statistically significant, before and after treatment with compression stockings, compared with the posterior tibial vein, for example, which did not.

Finally, with your findings, would you recommend that healthy people like you and me who may have a history of varicose vein disease in the family should wear compression stockings every day?

Thank you very much, Dr Buhs, for this interesting and significant paper. I thank the Society for the opportunity to discuss this very interesting paper.

Dr Chad L. Buhs. Thank you, Dr Simonian.

With regard to the first question, the implications of this study on venous hemodynamics are unknown. Anecdotally, in our study, evidence of reflux flow did develop in two subjects, but the relationship between the anatomic changes and any hemodynamic changes needs further study.

As to calf diameter, I am not sure why the calf diameter actually decreased significantly when subjects were wearing compression stockings. I can only assume it is from a volume change in the calf, and this would certainly relate to any pressure change, which we talked about in the third question.

With regard to bias, there was really no way that we could blind the subjects as to whether they were wearing the compression stockings. They had to know, so there certainly is some bias in that they did know which day they were wearing the compression stockings.

With regard to perforating veins and why we found this, I do not think that this was a technical problem. All examinations were done by the same sonographer with the same equipment; I cannot explain why there was the change, but I do not think that this was a technical problem.

About the peroneal vein, I can only say what we did find in the study, and that is that it did decrease in size. I am not sure why this happened, or why the other veins did not decrease, but it did.

About whether we should wear compression stockings, I am on my feet a lot, and I personally don't wear them. I know a lot of nursing personnel in this particular area who do wear them, and whether or not they will eventually help in preventing future chronic venous insufficiency is unknown and may need further prospective study.